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Short communication

Germination dimorphism in *Suaeda acuminata*: A new combination of dormancy types for heteromorphic seeds

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Abstract

Desert annual *Suaeda acuminata* produces two morphologically distinct types of seeds on the same plant. The main aims of our study were to compare germination characteristics of the dimorphic seeds, ascertain their dormancy types and give the hormonal explanation. The two seed types of *S. acuminata* absorbed water at different rates with brown seeds imbibing water faster. Germination percentages of brown seeds were significantly higher than those of black seeds in all temperature and light regimes tested. Eight weeks of cold stratification did not break dormancy of black seeds, whereas exogenous GA_3 promoted germination. Excised embryos of untreated black seeds produced normal seedlings. Contents of ZR, GA_3 and ABA of brown seeds were significantly higher than that of black seeds; while contents of IAA of black seeds were significantly higher than that of brown seeds. Brown seeds of *S. acuminata* are non-dormant, whereas black seeds have intermediate physiological dormancy (PD). Interaction among ZR, ABA and GA_3 may play an important role in dormancy status of both seed types. This is the first report of non-dormancy and intermediate PD in a heteromorphic species.
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1. Introduction

Generally speaking, each plant species produces only one morphological/physiological type of seed. However, some plants produce two or more distinct types of seeds on a single individual (Harper, 1977; Venable, 1985). This phenomenon is called seed heteromorphism. Most heteromorphic species are annuals, often in the Asteraceae or Chenopodiaceae that grow in extreme environments such as arid, semiarid and deserts (Mandák, 1997; Imbert, 2002). Heteromorphic seeds are found in more than 200 species, and they usually differ in color, size and shape, as well as in dispersal capacity and germination requirements (Sorensen, 1978; Khan and Ungar, 1984; Cheplick, 1994; Baskin and Baskin, 1998; Imbert, 2002; Lu et al., 2010).

Desert plants may develop various germination strategies that are adaptations to extreme environments (Gutterman, 1993). Heteromorphic seeds from a single plant growing in desert climate may represent a combination of divergent germination strategies (opportunistic vs cautious strategies) (Venable, 1985; Gutterman, 2002). Previous studies have shown that heteromorphic seeds usually have different germination characteristics (Baskin and Baskin, 1976; Venable and Levin, 1985; Brändel, 2007). For example, Mandák and Pyšek (2001a) compared germination of different fruit types of the heterocarpous *Atriplex sagittata* in different light and nitrogen supply conditions in the laboratory. They showed that heteromorphic seeds, produced by different types of fruits, have different germination percentages that are affected by light quality, nitrate concentration and cold stratification. A field study on germination of dimorphic seeds of *A. prostrata* and *Salicornia europaea* across zonal communities found that germination was >90% for large seeds of both species placed on the soil surface and that germination of small seeds was >50% and >75%, respectively (Carter and Ungar, 2003).

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Many papers reported differential germination of heteromorphic seeds, but few studies defined the dormancy class, level and type in the seeds (Philipupillai and Ungar, 1984; Baskin and Baskin, 1998; Carter and Ungar, 2003; Brändel, 2007). Dormancy characteristics of seeds of heteromorphic species can be sorted into two categories. Partial types are non-dormant and the others are dormant; all types of seeds are dormant. Large brown seeds of *A. sagittata* are non-dormant, medium black seeds are dormant and small black seeds are deeply dormant (Mandák and Pyšek, 2001a). All three types of achenes of the annual ephemeral species *Garhadiolus papposus* are dormant (Sun et al., 2009). Wang et al. (2008) reported that freshly-matured brown seeds of *Suaeda aralocaspica* are non-dormant and black seeds have non-deep type 2 physiological dormancy (PD). This was the first report of the combination of non-dormant and non-deep type 2 PD for heteromorphic seeds. We surmised that there are other combinations of dormancy types for heteromorphic species.

Former studies have attempted to correlate dormancy levels with interactions of hormones (Kucera et al., 2005). Changes in the contents of ABA, GA and cytokinins have been examined in many seeds and no consistent correlation between dormancy levels and hormone contents have been established (Khan and Samimy, 1982). In most studies, ABA is a positive regulator of dormancy induction and maintenance, while GA releases dormancy and counteracts ABA effects (Kucera et al., 2005). Heteromorphic seeds are unique biological models to test hormone regulation hypothesis because different seed types in the same plant have differential dormancy levels and germination characters.

We recently discovered that the desert annual halophyte *Suaeda acuminata* (Chenopodiaceae) produces dimorphic seeds (Ding et al., 2010). This species, native to central Asia, was reported to produce small black seeds (Delectis Florae Reipublicae Popularis Sinicae Agendae Academiae Sinicae Edita, 1979; Commissione Redactorum Florae Xinjiangensis, 1994). However, in addition to small black seeds, we observed large brown seeds on a single plant of *S. acuminata* in northern Xinjiang, China. Seed heteromorphism provides us with an optimal opportunity to study different dormancy types and dormancy-breaking mechanisms of the same plant species.

The goals of this study are to determine whether there is difference in germination of dimorphic seeds, and to ascertain the dormancy type (if any) of these seeds. Meanwhile, we use both seed types to test the theoretical prediction that hormone regulate seed dormancy. Specifically, we addressed three questions. (1) How do temperature and light affect germination of dimorphic seeds of *S. acuminata*? (2) Does seed type determine if seeds are dormant or non-dormant? If so, what type of dormancy does each type of seeds have? (3) What is the difference in contents of hormone between different seed types?

2. Materials and methods

2.1. Study species and sites

Suaeda acuminata L. (Chenopodiaceae) is a desert herb restricted to central Asia (Delectis Florae Reipublicae Popularis Sinicae Agendae Academiae Sinicae Edita, 1979). In China, *S. acuminata* is found only in the inland saline-alkaline deserts in Xinjiang province (Commissione Redactorum Florae Xinjiangensis, 1994). Field observations have shown that *S. acuminata* behaves as a summer annual in northern Xinjiang province, China. Germination occurs only in spring. Newly-germinated seedlings have been seen in late March, but most of the germination occurs in April. By late April, thousands of seedlings with only cotyledons are present. Plants begin to flower in mid-June, but the peak of flowering is from late June to mid-July. Seed dispersal begins in mid-July. In Flora of China and Flora Xinjiangensis, only one type of seed (red-brown to black, 0.8–1 mm and smooth) was described. However, we found two types of seeds on each plant of *S. acuminata*: brown with soft coarse seed coat and black with rigid smooth seed coat.

The research area is an inland cold desert (87° 46′ 10″ E; 44° 07′ 55″ N; 500 m a.s.l) with typical temperate desert climate. Associates of *S. acuminata* include *Kalidium caspicum*, *S. microphylla*, *S. physophora*, *Petrosimonia sibirica* (Chenopodiaceae) and *Peganum harmala* (Zygophyllaceae). Mean annual temperature is 6.8 °C, mean temperature of warmest month (July) is 25.6 °C, and mean temperature of coldest month (January) is −16.9 °C. Annual precipitation (rain and snow) is about 200 mm.

2.2. Seeds

Plants of *S. acuminata* grew under a low competitive environment in a salt desert near the Fukang Desert Ecological Station of the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. Mature fruits were collected from ca. 200 plants that were not shaded on 10 October 2009. Fruits were collected randomly from the entire plant in a population. The fruits were allowed to dry for 10 days, and then the seeds were cleaned and separated by their colour. Germination experiments and cold stratification treatment were started on 28 October 2009. Other seeds were stored dry (relative humidity: 25–28%) at 4 °C until used in experiments.

Diameter and thickness of 20 seeds of each of the two seed types were measured, and four groups of 100 seeds of each type were weighed to determine seed mass.

2.3. Imbibition tests

Imbibition tests were conducted at room temperature (19–23 °C, 30% relative humidity) using four replicates of 25 dry seeds of each morph. Seeds were placed in 90-mm-diameter Petri dishes with distilled water-moistened filter paper. Then, seed mass was measured at time 0 and after 1, 3, 6, 9, 12, 22 h. The imbibition test of brown seeds was terminated after 6 h because the seeds had begun to germinate. The relative increase in fresh weight (W_r) of seeds was calculated as $W_r = [(W_f - W_i)/W_i] \times 100$, where W_i is the initial seed weight and W_f the weight after a certain time (Baskin et al., 2004).

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